PCT/GB2004/004114
GB04/04114

INVESTOR IN PEOPLE


The Patent Office
Concept House
Cardiff Road
Newport
South Wales
NP10 8QQ


REC'D 19 OCT 2004
WIPO PCT

# PRIORITY DOCUMENT

SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation & Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

n accordance with the rules, the words "public limited company" may be replaced by p.l.c., lc, P.L.C. or PLC.

-registration under the Companies Act does not constitute a new legal entity but merely jects the company to certain additional company law rules.

Signed K Behan

Dated 11 October 2004

Patents Form 1/77

Patents Act 1977
(Rule 16)

30 SEP 2003

The Patent Office

1/77

# Request for grant of a patent

*(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)*

The Patent Office
01OCT03 E841105-1 D02805
P01/7700 0.00-0322883
Cardiff Road
Newport
South Wales
NP10 8QQ

1. Your reference — M03B312/ASB

2. Patent application number *(The Patent Office will fill in this part)* — 30 SEP 2003 — 0322883.0

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

   The BOC Group plc, Chertsey Road, Windlesham, Surrey, GU20 6HJ

   Patents ADP number *(if you know it)* — 884627002 — 07975949001

   If the applicant is a corporate body, give the country/state of its incorporation — England

4. Title of the invention — VACUUM PUMP

5. Name of your agent *(if you have one)* — Andrew Steven BOOTH

   "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

   The BOC Group plc, Chertsey Road, Windlesham, Surrey, GU20 6HJ

   Patents ADP number *(if you know it)* — 07975949001

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

| Country | Priority application number *(if you know it)* | Date of filing *(day / month / year)* |
| --- | --- | --- |
| | | |

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

| Number of earlier application | Date of filing *(day / month / year)* |
| --- | --- |
| | |

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
   *a) any applicant named in part 3 is not an inventor, or*
   *b) there is an inventor who is not named as an applicant, or*
   *c) any named applicant is a corporate body.*
   *See note (d))*

   Yes

9. I... r the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

| | |
|---|---|
| Continuation sheets of this form | 0 |
| Description | 9 |
| Claim(s) | 4 |
| Abstract | 1 |
| Drawing(s) | 3 +3 |

10. If you are also filing any of the following, state how many against each item.

| | |
|---|---|
| Priority documents | 0 |
| Translations of priority documents | 0 |
| Statement of inventorship and right to grant of a patent *(Patents Form 7/77)* | 0 |
| Request for preliminary examination and search *(Patents Form 9/77)* | 1 |
| Request for substantive examination *(Patents Form 10/77)* | 0 |
| Any other documents *(please specify)* | 0 |

11. I/We request the grant of a patent on the basis of this application.

Signature A S Booth    Date 30/09/2003

12. Name and daytime telephone number of person to contact in the United Kingdom    Andrew Steven Booth (01276) 807612

**Warning**

*After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publication or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977. You will be informed if it is necessary to prohibit or restrict your invention in this way. Furthermore, if you live in the United Kingdom, Section 23 of the Patents Act 1977 stops you from applying for a patent abroad without first getting written permission from the Patent Office unless an application has been filed at least 6 weeks beforehand in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction has been revoked.*

**Notes**

a) *If you need help to fill in this form or you have any questions, please contact the Patent Office on 08459 500505.*

b) *Write your answers in capital letters using black ink or you may type them.*

c) *If there is not enough space for all the relevant details on any part of this form, please continue on a separate sheet of paper and write "see continuation sheet" in the relevant part(s). Any continuation sheet should be attached to this form.*

d) *If you have answered 'Yes' Patents Form 7/77 will need to be filed.*

*Once you have filled in the form you must remember to sign and date it.*

*For details of the fee and ways to pay please contact the Patent Office.*

# VACUUM PUMP

This invention relates to a vacuum pump and in particular a compound vacuum pump with multiple ports suitable for differential pumping of multiple chambers.

In a differentially pumped mass spectrometer system a sample and carrier gas are introduced to a mass analyser for analysis. One such example is given in Figure 1. With reference to Figure 1, in such a system there exists a high vacuum chamber 10 immediately following first and second evacuated interface chambers 12, 14. The first interface chamber 12 may include a first ion guide for guiding ions from the ion source into the second interface chamber 14, and the second, middle chamber 14 may include a second ion guide for guiding ions from the first interface chamber into the high vacuum chamber 10. In this example, in use, the first interface chamber is at a pressure of around 1 mbar, the second interface chamber is at a pressure of around $10^{-3}$mbar, and the high vacuum chamber is at a pressure of around $10^{-5}$mbar.

The high vacuum chamber 10 and second interface chamber 14 can be evacuated by means of a compound vacuum pump 16. In this example, the vacuum pump has two pumping sections in the form of two sets 18, 20 of turbo-molecular stages, and a third pumping section in the form of a Holweck drag mechanism 22; an alternative form of drag mechanism, such as a Siegbahn or Gaede mechanism, could be used instead. Each set 18, 20 of turbo-molecular stages comprises a number (three shown in Figure 1, although any suitable number could be provided) of rotor 19a, 21a and stator 19b, 21b blade pairs of known angled construction. The Holweck mechanism 22 includes a number (two shown in Figure 1 although any suitable number could be provided) of rotating cylinders 23a and corresponding annular stators 23b and helical channels in a manner known per se.

In this example, a first pump inlet 24 is connected to the high vacuum chamber 10, and fluid pumped through the inlet 24 passes through both sets 18, 20 of turbo-

molecular stages in sequence and the Holweck mechanism 22 and exits the pump via outlet 30. A second pump inlet 26 is connected to the second interface chamber 14, and fluid pumped through the inlet 26 passes through set 20 of turbo-molecular stages and the Holweck mechanism 22 and exits the pump via outlet 30. In this example, the first interface chamber 12 may be connected to a backing pump (not shown), which may also pump fluid from the outlet 30 of the compound vacuum pump 16. As fluid entering each pump inlet passes through a respective different number of stages before exiting from the pump, the pump 16 is able to provide the required vacuum levels in the chambers 10, 14..

In order to increase system performance, it is desirable to increase the mass flow rate of the sample and carrier gas from the source into the high vacuum chamber 10. For the pump illustrated in Figure 1, this could be achieved by increasing the capacity of the compound vacuum pump 16 by increasing the diameter of the rotors 21a and stators 21b of set 20. For example, in order to double the capacity of the pump 16, the area of the rotors 21a and stators 21b would be required to double in size. In addition to increasing the overall size of the pump 16, and thus the overall size of the mass spectrometer system, the pump 16 would become more difficult to drive in view of the increased mass acting on the drive shaft 32 due to the larger rotors and stators of set 20.

It is an aim of the present invention to provide a differential pumping, multi port, compound vacuum pump, which can enable the mass flow rate in the system to be increased specifically where required without significantly increasing the size of the pump.

In a first aspect, the present invention provides a vacuum pump comprising a first pumping section and, downstream therefrom, a second pumping section, a first pump inlet through which fluid can enter the pump and pass through both the first pumping section and the second pumping sections towards a pump outlet, and a second pump inlet through which fluid can enter the pump and pass through, of said sections, only the second pumping sections towards the outlet, wherein at

least one of the first and second pumping sections, preferably the second pumping section, comprises an externally threaded rotor.

Thus, the second, turbo-molecular pumping section 20 of the known pump described with reference to Figure 1 is effectively replaced by a pumping section having an externally threaded, or helical, rotor. In such an arrangement, the inlet of the helix will behave in use like a rotor of a turbo-molecular stage, and thus provide a pumping action through both axial and radial interactions. In comparison, a Holweck mechanism with a static thread, such as that indicated at 22 in Figure 1, pumps fluid by nominally radial interactions between the thread and cylinder. Beyond a certain radial depth of thread, this mechanism becomes less efficient due to the reducing number of radial interactions, and it is for this reason that the typical capacity of a "static" Holweck mechanism is limited to less than that of an equivalent diameter turbo-molecular stage, which pumps by nominally axial interactions and has greater radial blade depths. By providing an externally threaded rotor, the inlet of the thread of the externally threaded rotor can be made much deeper radially than the helical groove in a static Holweck mechanism, resulting in a significantly higher pumping capacity. By appropriate design, the capacity of an externally threaded, deep grooved helical rotor can be comparable to that of an equivalent diameter turbomolecular stage when operating at low inlet pressures, for example below $10^{-3}$ mbar. The advantage of the use of such a deep groove helical rotor in place of a turbomolecular stage is that it can offer a higher capacity at higher inlet pressures (above $10^{-3}$ mbar) with lower levels of power consumption / heat generation – a limiting factor of the operational window of turbomolecular pumps. By utilising a deep groove helical rotor and raising the inlet pressure above that which would be ideal for a turbomolecular pump, more flow can be pumped without requiring an increase in effective pumping capacity, thus meeting the requirements of increased mass spectrometer performance without increasing the size of the pump envelope.

Minimising the increase in pump size/length whilst increasing the system performance where required can make the pump particularly suitable for use as a

compound pump for use in differentially pumping multiple chambers of a bench-top mass spectrometer system requiring a greater mass flow rate at, for example, the middle chamber to increase the flow rate into the analyser with a minimal increase in pump size.

As the molecules transfer from the inlet side of the rotor towards the outlet side, the pumping action is similar to that of a static Holweck mechanism, and is due to radial interactions. Therefore, the helical rotor preferably has a tapering thread depth from inlet to outlet (preferably deeper at the inlet side than at the outlet side). Furthermore, the helical rotor preferably has a different helix angle at the inlet side than at the outlet side; both the thread depth and helix angle are preferably reduced smoothly along the axial length of the pumping section from the inlet side towards the outlet side.

In a preferred arrangement, the first pumping section comprises at least one turbo-molecular stage, preferably at least three turbo-molecular stages. The first and second pumping sections may be of a different size/diameter. This can offer selective pumping performance.

Thus, preferably the helical rotor is located downstream from said at least one turbo-molecular stage. To ensure that fluid enters the helical rotor with maximum relative velocity to the helix blades, and thereby optimise pumping performance, the turbo-molecular stage is preferably arranged such that the molecules of fluid entering the helical rotor have been emitted from the surface of a stator of the turbomolecular stage by placing a stator stage as the final stage of the turbomolecular section adjacent the inlet side of the helical rotor.

The pump preferably comprises a third pumping section, preferably a molecular drag stage, such as a Holweck stage, or an aerodynamic pumping stage, downstream from the first and second pumping sections for receiving fluid therefrom and outputting fluid towards the outlet. The third pumping section preferably comprises a helical groove formed in a stator thereof. By providing a

Holweck stage offering static surfaces adjacent to the outlet of the helical rotor stage, pump performance can be further optimised.

Thus, in a second aspect, the present invention provides a vacuum pump comprising a first pumping section, a second pumping section downstream from the first pumping section, a third pumping section downstream from the second pumping section, a first pump inlet through which fluid can enter the pump and pass through each of the pumping sections towards a pump outlet, and a second pump inlet through which fluid can enter the pump and pass through only the second and the third pumping sections towards the outlet, wherein the third pumping section comprises a helical groove formed in a stator thereof, and at least one of the first and second pumping sections comprises a helical groove formed in a rotor thereof.

Preferably, the depth of the groove of said at least one of the first and second pumping sections at the inlet side thereof is greater than the depth of the groove of the third pumping section at the inlet side thereof.

In a third aspect, the present invention provides a vacuum pump comprising a first pump inlet, a pump outlet, a second pump inlet located between the first pump inlet and the pump outlet, and an externally threaded rotor having an inlet adjacent the second pump inlet.

The invention also provides a differentially pumped mass spectrometer system comprising two chambers and a pump as aforementioned for evacuating each of the chambers.

The present invention also provides a differentially pumped mass spectrometer system comprising a mass spectrometer having a plurality of pressure chambers; a vacuum pump attached thereto and comprising a plurality of pump inlets each for receiving fluid from a respective pressure chamber, and a plurality of pumping

stages for differentially pumping the chambers; wherein at least one of the pumping stages comprises an externally threaded rotor.

Preferred features of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a simplified cross-section through a known multi port vacuum pump suitable for evacuating a differentially pumped, mass spectrometer system;

Figure 2 is a simplified cross-section through an embodiment of a multi port vacuum pump suitable for evacuating the differentially pumped mass spectrometer system of Figure 1; and

Figure 3 illustrates an externally threaded rotor of the pump of Figure 2.

With reference to Figure 2, an embodiment of a vacuum pump 100 suitable for evacuating at the least the high vacuum chamber 10 and intermediate chamber 14 of the differentially pumped mass spectrometer system described above with reference to Figure 1 comprises a multi-component body 102 within which is mounted a shaft 104. Rotation of the shaft is effected by a motor (not shown), for example, a brushless dc motor, positioned about the shaft 104. The shaft 104 is mounted on opposite bearings (not shown). For example, the drive shaft 104 may be supported by a hybrid permanent magnet bearing and oil lubricated bearing system.

The pump includes at least two pumping sections 106, 108 and, optionally, a third pumping section 112. The first pumping section 106 comprises a set of turbo-molecular stages. In the embodiment shown in Figure 2, the set of turbo-molecular stages 106 comprises three rotor blades and three stator blades of known angled construction. A rotor blade is indicated at 107a and a stator blade is indicated at 107b. In this example, the rotor blades 107a are integral with the drive shaft 104.

The second pumping section 108 comprises an externally threaded rotor 109, as shown in more detail in Figure 3. The rotor 109 comprises a bore 110 through which passes the drive shaft 104, and an external thread 111a defining a helical groove 111b. Alternatively, in the embodiment shown in Figure 2, the rotor 109 is integral with the drive shaft 104. The depth of the thread 111a, and thus the depth of the groove 111b, can be designed to taper from the inlet side 111c of the rotor 109 towards the outlet side 111d. In this embodiment, the thread 111a is deeper at the inlet side than at the outlet side, although this is not essential. The helix angle, namely the angle of inclination of the thread to a plane perpendicular to the axis of the shaft 104, of the rotor can also vary from the inlet side to the outlet side; in this embodiment, the helix angle is shallower at the outlet side than at the inlet side, although again this is not essential.

Optionally, as shown in Figure 2, downstream of the first and second pumping sections is a third pumping section 112 in the form of a Holweck or other type of drag mechanism. In this embodiment, the Holweck mechanism comprises two rotating cylinders 113a, 113b and corresponding annular stators 114a, 114b having helical channels formed therein in a manner known per se. The rotating cylinders 113a, 113b are preferably formed from a carbon fibre material, and are mounted on a disc 115, which is located on the drive shaft 104. In this example, the disc 115 is also integral with the drive shaft 104. Downstream of the Holweck mechanism 112 is a pump outlet 116.

As illustrated in Figure 2, the pump 100 has two inlets; although only two inlets are used in this embodiment, the pump may have three or more inlets, which can be selectively opened and closed and can, for example, make the use of internal baffles to guide different flow streams to particular portions of a mechanism. The first, low fluid pressure inlet 120 is located upstream of all of the pumping sections. The second, high fluid pressure inlet 122 is located interstage the first pumping section 106 and the second pumping section 108.

In use, each inlet is connected to a respective chamber of the differentially pumped mass spectrometer system. Fluid passing through the first inlet 120 from the low pressure chamber 10 passes through each of the pumping sections 106, 108, 112 and exits the pump 100 via pump outlet 116. To ensure that fluid enters the helical rotor 109 of the second pumping stage 108 with maximum relative velocity to the helix blades (threads), and thereby optimise pumping performance, in this embodiment the first pumping section 106 is arranged such that the molecules of fluid entering the helical rotor 109 have been emitted from the surface of the final stator 107c of that section 106, and the subsequent stage of the Holweck mechanism 112 is also stationary to offer static surfaces at the outlet side 111d of the rotor 109.

Fluid passing through the second inlet 122 from the middle pressure chamber 14 enters the pump 100 and passes through pumping sections 108, 112 only and exits the pump via outlet 116. Fluid passing through a third inlet 124 from the high pressure chamber 12 may be pumped by a backing pump (not shown) which also backs the pump 100 via outlet 116.

In this embodiment, in use, the first interface chamber 12 is at a pressure of around 1 mbar, the second interface chamber 14 is at a pressure of around $10^{-2}$-$10^{-3}$ mbar, and the high vacuum chamber 10 is at a pressure of around $10^{-5}$ mbar. Thus, in comparison to the example illustrated in figure 1, the pressure in the second interface chamber 14 is increased in the embodiment shown in Figure 2. By increasing the pressure to around $10^{-2}$mbar, which pressure difference would not affect significantly the function of the mass spectrometer system, the requirements on pumping speed are reduced by the ratio of the old to the new pressure for a fixed flow. Therefore, for example, if the pressure is raised 10-fold, and the flow rate is doubled, the pumping speed at this new pressure can be reduced 5-fold, although in use it would clearly be beneficial to maintain as high a pumping speed as possible to maximise the flow rate from the second interface chamber 14. A turbo-molecular pumping section such as that indicated at 20 in Figure 1 would not be as effective as the pumping section 108 in Figure 2 at

maintaining a pressure of around $10^{-2}$mbar in the second interface chamber 14, and would in use consume more power, generating more heat than pumping section 108 and potentially have less performance due to operating further outside its effective performance range.

Thus, a particular advantage of the embodiment described above is that the mass flow rate of fluid entering the pump from the middle chamber 14 can be at least doubled in comparison to the known arrangement shown in Figure 1 without any increase in the size of the pump. In view of this, the flow rate of the sample entering the high vacuum chamber 10 from the middle chamber can also be increased, increasing the performance of the differentially pumped mass spectrometer system.

**CLAIMS**

1. A vacuum pump comprising a first pumping section and, downstream therefrom, a second pumping section, a first pump inlet through which fluid can enter the pump and pass through both the first pumping section and the second pumping sections towards a pump outlet, and a second pump inlet through which fluid can enter the pump and pass through, of said sections, only the second pumping sections towards the outlet, wherein at least one of the first and second pumping sections comprises an externally threaded rotor.

2. A pump according to Claim 1, wherein the externally threaded rotor comprises a helical groove.

3. A pump according to Claim 2, wherein the depth of the helical groove varies from the inlet side thereof to the outlet side thereof.

4. A pump according to Claim 2 or Claim 3, wherein the depth of the helical groove decreases from the inlet side thereof to the outlet side thereof.

5. A pump according to any of Claims 2 to 4, wherein the inclination of the groove varies from the inlet side thereof to the outlet side thereof.

6. A pump according to any of Claims 2 to 5, wherein the inclination of the groove decreases from the inlet side thereof to the outlet side thereof.

7. A pump according to any preceding claim, wherein the second pumping section comprises said externally threaded rotor.

8. A pump according to Claim 7, wherein the first pumping section comprises at least one turbo-molecular stage.

9. A pump according to Claim 7 or Claim 8, wherein the first pumping section comprises at least three turbo-molecular stages.

10. A pump according to Claim 8 or Claim 9, wherein the turbo-molecular stage is arranged such that, in use, molecules of fluid entering the external thread therefrom are emitted from the surface of a stator thereof.

11. A pump according to any preceding claim, comprising at least one additional pumping section downstream from the first and second pumping sections for receiving fluid therefrom and outputting fluid towards the outlet.

12. A pump according to Claim 11, wherein said at least one additional pumping section comprises a molecular drag stage or an aerodynamic pumping stage.

13. A pump according to Claim 12, wherein the additional pumping section comprises a helical groove formed in a stator thereof.

14. A vacuum pump comprising a first pumping section, a second pumping section downstream from the first pumping section, a third pumping section downstream from the second pumping section, a first pump inlet through which fluid can enter the pump and pass through each of the pumping sections towards a pump outlet, and a second pump inlet through which fluid can enter the pump and pass through only the second and the third pumping sections towards the outlet, wherein the third pumping section comprises a helical groove formed in a stator thereof, and at least one of the first and second

pumping sections comprises a helical groove formed in a rotor thereof.

15. A pump according to Claim 14, wherein the depth of the groove of said at least one of the first and second pumping sections at the inlet side thereof is greater than the depth of the groove of the third pumping section at the inlet side thereof.

16. A vacuum pump comprising a first pump inlet, a pump outlet, a second pump inlet located between the first pump inlet and the pump outlet, and an externally threaded rotor having an inlet adjacent the second pump inlet.

17. A pump according to Claim 16, comprising a turbo-molecular stage having an inlet side adjacent the first pump inlet.

18. A vacuum pump substantially as herein described with reference to Figure 2 of the accompanying drawings.

19. A differentially pumped mass spectrometer system comprising two chambers and a pump according to any preceding claim for evacuating each of the chambers.

20. A differentially pumped mass spectrometer system comprising a mass spectrometer having a plurality of pressure chambers; a vacuum pump attached thereto and comprising a plurality of pump inlets each for receiving fluid from a respective pressure chamber, and a plurality of pumping stages for differentially pumping the chambers; wherein at least one of the pumping stages comprises an externally threaded rotor.

21. A system according to Claim 20, wherein the pump comprises a first pump inlet, a pump outlet, and a second pump inlet located between the first pump inlet and the pump outlet, wherein the inlet of the externally threaded rotor is adjacent the second pump inlet.

22. A system according to Claim 20 or Claim 21, wherein at least one of the pumping stages arranged to pump fluid from a chamber in which a pressure of at least $10^{-3}$mbar is to be generated comprises an externally threaded rotor.

23. A system according to any of Claims 20 to 22, wherein at least one of the pumping stages arranged to pump fluid from a chamber in which a pressure of at least $5x10^{-3}$mbar is to be generated comprises an externally threaded rotor.

24. A differentially pumped mass spectrometer system substantially as herein described with reference to Figure 2 of the accompanying drawings.

## ABSTRACT

A vacuum pump comprises a first pumping section 106, and, downstream therefrom, a second pumping section 108. The pump comprises a first pump inlet 120 through which fluid can enter the pump and pass through both the first and second pumping sections towards a pump outlet, and a second pump inlet 122 through which fluid can enter the pump and pass through only the second pumping section towards the outlet. The second pumping section 108 comprises an externally threaded rotor 109.

(Figure 2)

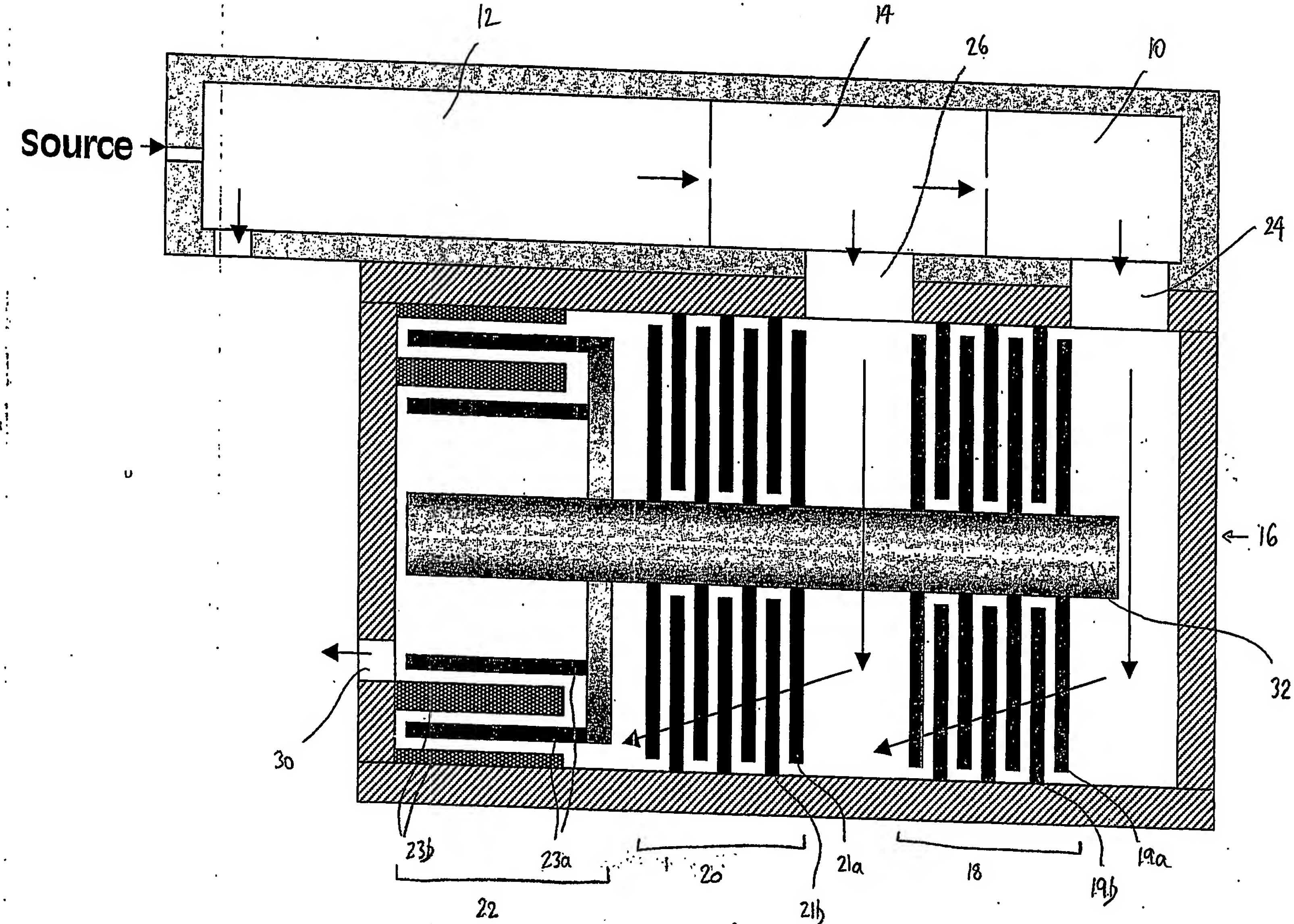
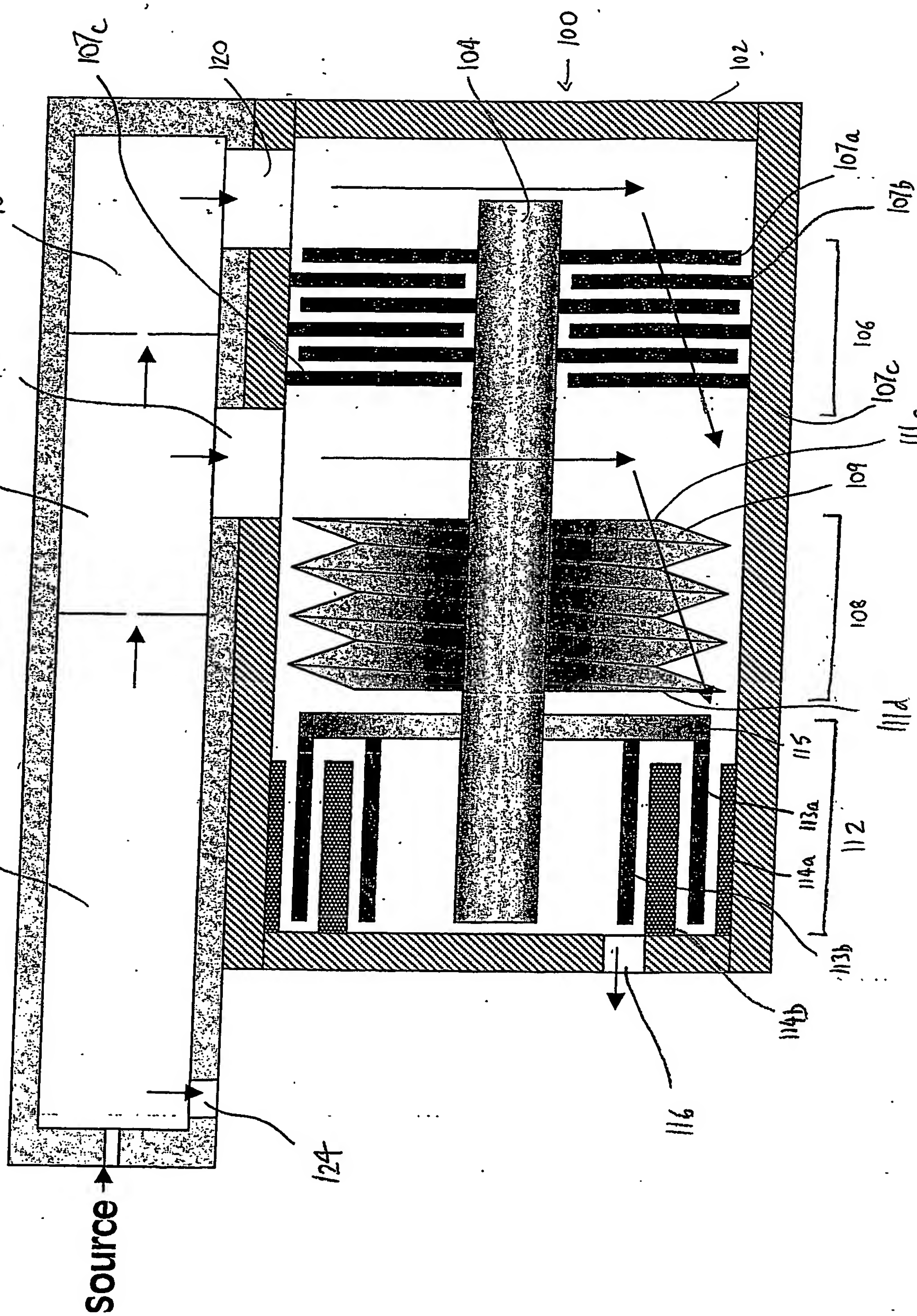



FIG. 1 (PRIOR ART)



100
102
104
106
107a
107b
107c
107c
108
109
10
111c
111d
112
113a
113b
114a
114b
115
116
12
120
122
124
14
Source


FIG. 2

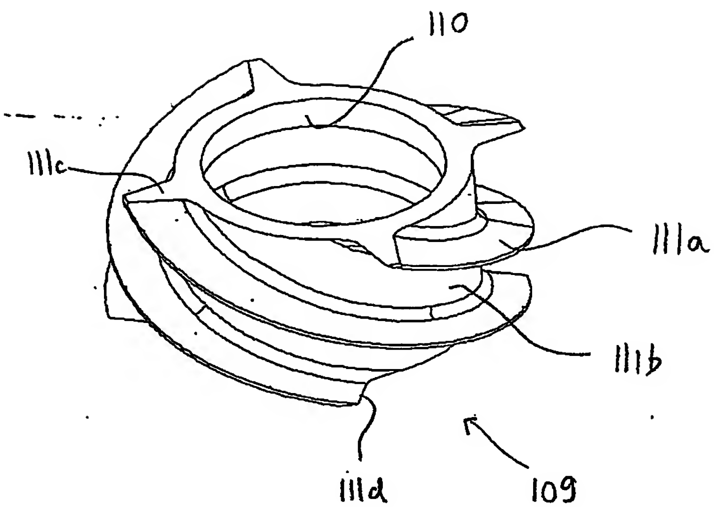



FIG. 3